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A request for correction of the description has been filed pursuant to Rule 88 EPC. A decision on the request will be taken during the proceedings before the Examining Division (Guidelines for Examination in the EPO, A-V, 3.).

(54) Integrated resistive element, phase-change memory element including said resistive element, and method of manufacture thereof

(57) A vertical-current-flow resistive element (12) comprising a monolithic region (12) having a first portion (12a) and a second portion (12b) arranged on top of one another and formed by a single material. The first portion has a first resistivity, and the second portion (12b) has a second resistivity, lower than the first resistivity. To this aim, a monolithic region with a uniform resistivity and a height greater than at least one of the other dimensions is first formed; then the resistivity of the first portion (12a) is increased by introducing, from the top, species that form a prevalently covalent bond with the conductive material of the monolithic region, so that the concentration of said species becomes higher in the first portion (12a) than in the second portion (12b). Preferably, the conductive material is a binary or ternary alloy, chosen from among TiAl, TiSi₂, Ta, WSi, and the increase in resistivity is obtained by nitridation.

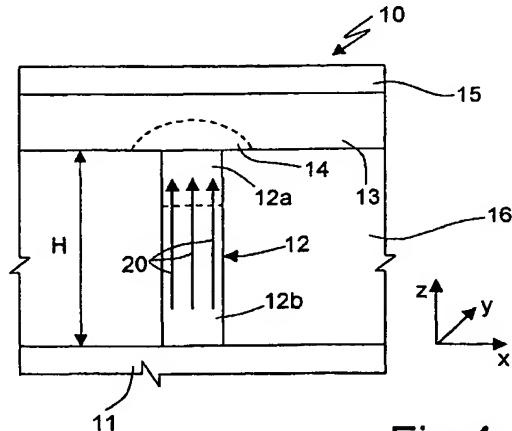


Fig.4

Description

[0001] The present Invention relates to an integrated resistor, a phase-change memory element including this resistor, and a process for the fabrication thereof.

[0002] As is known, phase-change memory elements, or PCM elements, exploit the characteristics of a class of materials able to change between two phases having distinct electrical characteristics. For example, these materials may change from an amorphous, disorderly phase to a crystalline or polycrystalline, orderly phase, and the two phases are associated to considerably different values of resistivity.

[0003] At present, alloys of elements of group VI of the periodic table, such as Te or Se, referred to as chalcogenides or chalcogenic materials, can advantageously be used in phase-change cells. The chalcogenide that currently offers the most promise is formed by a Ge, Sb and Te alloy ($Ge_2Sb_2Te_5$) and is widely used for storing information in overwritable disks.

[0004] In chalcogenides, the resistivity varies by two or more orders of magnitude when the material passes from the amorphous phase (more resistive) to the crystalline phase (more conductive) and vice versa. The characteristics of the chalcogenides in the two phases are shown in Figure 1. As may be noted, at a given read voltage, here designated by V_r , there is a resistance variation of more than 10.

[0005] Phase change may be obtained by locally increasing the temperature, as shown in Figure 2. Below 150°C both phases are stable. Above 200°C (nucleation start temperature, designated by T_x), fast nucleation of the crystallites takes place, and, if the material is kept at the crystallization temperature for a sufficient length of time (time t_2), it changes its phase and becomes polycrystalline. To bring the chalcogenide back into the amorphous state, it is necessary to raise the temperature above the melting temperature T_m (approximately 600°C) and then to cool the chalcogenide off rapidly (time t_1).

[0006] From the electrical standpoint, it is possible to reach both the critical temperatures, namely crystallization and melting temperature, by causing a current to flow through a resistive element which heats the chalcogenide material by Joule effect.

[0007] The basic structure of a phase-change memory element 1 which operates according to the principles described above is shown in Figure 3 and comprises a resistive element 2 (heater) and a programmable element 3. The programmable element 3 is made of a chalcogenide and is normally in the polycrystalline state in order to enable a good flow of current. One part of the programmable element 3 is in direct contact with the resistive element 2 and forms the area involved in the phase change, hereinafter referred to as phase-change portion 4.

[0008] If an electric current having an appropriate value is made to pass through the resistive element 2, it is

possible to heat the phase-change portion 4 selectively up to the crystallization temperature or to the melting temperature and to cause phase change. In particular, if a current I is made to pass through a resistive element

5 2 having resistance R , the heat generated is equal to I^2R .

[0009] At present, the resistive element 2 is obtained by deposition -using PVD (Physical Vapor Deposition), Reactive PVD and CVD (Chemical Vapor Deposition)- of materials, such as TaAIN, TiSiN, TaN or, more in general, binary or ternary alloys having a resistivity of between a few hundred $\mu\Omega\text{cm}$ and a few ten $m\Omega\text{cm}$. The material thus obtained has a substantially homogeneous resistance in all directions.

[0010] 15 The memory element described above is disadvantageous since it has a high dissipation on account of the high resistance of the resistive element, even if the portion useful for generating the phase change heat for the memory element 1 is only one part of its volume.

20 A high level of dissipation may, in fact, be harmful for the materials and components integrated in the chip. The problems associated to dissipation of the entire resistive element moreover impose design constraints on the values of resistivity that can be used for the resistive element, as well as on the programming currents and voltages, giving rise to high levels of consumption.

[0011] 25 The aim of the present invention is therefore to provide a resistive element that overcomes the described disadvantages.

[0012] 30 According to the present invention there are provided an integrated resistor, a phase-change memory element, and a process for the fabrication of an integrated resistor, as defined in claims 1, 11 and 13, respectively.

[0013] 35 For a better understanding of the present invention, a preferred embodiment thereof is now described, purely by way of non-limiting example, with reference to the attached drawings, wherein:

- 40 - Figure 1 shows the current-versus-voltage characteristic of a phase-change material;
- Figure 2 shows the temperature-versus-current plot of a phase-change material;
- Figure 3 shows the basic structure of a PCM element;
- Figure 4 is a cross-section of a resistive element according to the invention;
- Figure 5 presents a concentration plot of ions designed to increase the resistivity of the resistive element of Figure 4; and
- Figures 6, 7 and 8 are top plan views of the resistive element of Figure 4, according to three different embodiments.

[0014] 55 Figure 4 shows a PCM memory element 10 comprising a bottom electrode 11, of electrically conductive material; an insulating layer 16, arranged on top of the bottom electrode 11; a resistive element 12, which

extends vertically inside the insulating layer 16 and is in contact with the bottom electrode 11; a polycrystalline layer 13, which extends on top of the insulating layer 16 and has a portion in contact with the resistive element 12, hereinafter referred to as phase-change portion 14; and a top electrode 15, of conductive material, which extends on top of the polycrystalline layer 13.

[0015] The resistive element 12, of overall height H, is of the vertical-current-flow type and has a height or thickness H in the Z direction much greater than at least one of the other dimensions (width in the X direction and depth in the Y direction). In particular, the resistive element 12 may be column-shaped, with a depth (in the Y direction) comparable to the width in the X direction, as shown in the schematic top plan view of Figure 6, or else wall-shaped, having a depth much greater than the width in the X direction, as shown in the schematic plan view of Figure 7, or yet again may have a closed shape, as shown in the schematic top plan view of Figure 8.

[0016] The resistive element 12 comprises a first portion 12a, having high resistivity, and a second portion 12b, of lower resistivity, arranged on top of one another. In the example illustrated, the first portion 12a is arranged at the top, and the second portion 12b is arranged at the bottom. The resistivity of the resistive element 12 may vary gradually, or else sharply, between the first portion 12a and the second portion 12b.

[0017] The resistive element 12 of Figure 4 is obtained starting from a material having an intrinsically medium-to-low resistivity, such as TiAl, TiSi₂, Ta, WSi, or another binary or ternary alloy with similar characteristics, and is subsequently treated so as to increase the resistivity of the first portion 12a with respect to the second portion 12b.

[0018] Preferably, the starting material of the resistive element 12 is enriched with nitrogen ions or nitrogen radicals, so as to increase local resistivity. For example, the enrichment may be achieved by plasma implantation or nitridation. Possibly, afterwards the resistive element 12 may be subjected to a thermal process whereby the introduced nitrogen forms amorphous, temperature-stable clusters.

[0019] As is known, nitrogen contributes to forming covalent bonds, rather than metallic bonds, and consequently determines a decrease in the electrons present in the conduction band, and thus increases the value of resistivity of the material into which it has been introduced.

[0020] Figure 5 shows the distribution of the nitrogen-ion content in the vertical direction (Z axis) inside the resistive element 12, after nitridation. In the example illustrated, in the first portion 12A (the top one) there is a concentration of nitrogen ions which to a first approximation is constant and has a higher value, corresponding to a high resistivity, whereas in the second portion 12b (the bottom one) the concentration of nitrogen ions is smaller and decreases almost down to zero in proximity of the interface with the bottom electrode 11. For

example, the first portion 12a has a resistivity of approximately 10 mΩcm, whilst in the second portion 12b the resistivity is reduced to approximately 1 mΩcm. The profile of the nitrogen concentration, and hence of the resistivity, can in any case be engineered according to the particular requirements.

[0021] As indicated in Figure 4 by the arrows 20, the current flows in a vertical direction (Z direction), i.e. parallel to the height of the resistive element 12, in contrast to barrier regions, made of similar alloys, wherein normally the thickness of the layer is much smaller than its width, and the current flows in a direction transverse to the larger dimension (width). In barrier regions, moreover, the resistivity is approximately uniform in the direction of the flow of current.

[0022] The resistive element 12 of Figure 4 is obtained as described hereinafter. After depositing and patterning the bottom electrode 11, on top of the substrate (not shown) the insulating layer 16 is deposited and planarized, so as to have, at the end, a height H. The insulating layer 16 is then etched to form an opening where the resistive element 12 is to be made.

[0023] Next, the starting material of the resistive element 12, for example TiAl, TiSi₂, Ta, or WSi, is deposited, and the excess material is removed from the surface of the insulating layer 16, for example by etch-back or CMP (Chemical Mechanical Polishing).

[0024] The resistive element 12 is then nitridated, for instance by an N implantation or a nitrogen-plasma implantation ("Remote Plasma Nitridation" or "Decoupled Plasma Nitridation"), or, in general, using any process that generates reactive nitrogen species (nitrogen ions or nitrogen radicals). The processes enable engineering of the nitrogen profile in the Z direction (as shown, for example, in Figure 5), thus enabling modulation of the resistivity of the resistive element 12. Preferably, the nitridation step is carried out without the use of masks.

[0025] Next, the polycrystalline layer 13 and the layer intended to form the top electrode 15 are deposited and are then defined so as to form a strip that extends perpendicular (at least locally) to the resistive element 12. In practice, the width direction of the resistive element 12 is parallel to the direction of extension of the strip in the area of mutual contact.

[0026] The advantages of the resistive element described are illustrated hereinafter. First, modulation of the resistivity in the vertical direction enables minimization of the heat dissipation and of the voltage drop in the portion distant from the phase-change region 14 (second portion 12b in contact with the bottom electrode 11) and maximization of the same quantities in the first portion (i.e., the one in contact with the phase-change region 14), where it is important to have a good generation of heat in order to control phase change of the phase-change region 14. Thus a high local dissipation of heat is obtained in contact with the phase-change region 14 and a low dissipation elsewhere, with a consequent reduction in the risks of damage to the materials and com-

ponents integrated in the chip.

[0027] The optimization of the resistivity profile moreover enables the use of programming voltages and currents lower than those required for a uniform resistive element. Consequently, it is possible to achieve better performance of the device, reduce energy consumption, and simplify the design of the components intended to generate and transport said currents and voltages.

[0028] Finally, it is clear that numerous modifications and variations may be made to the resistive element described and illustrated herein, all falling within the scope of the invention, as defined in the attached claims. For example, using a heavy implantation, it is possible to nitride preferentially the deep portion of the resistive element 12, obtaining a nitrogen and resistivity profile opposite to the one of Figure 5. In addition, by engineering the nitridation technique, it is possible to modify the concentration profile so as to obtain, instead of a gradual reduction of the resistivity in the second portion, a sharp reduction of the resistivity, or else so as to obtain a portion of reduced thickness with a high resistivity, or yet again a profile with gradual variation of the resistivity throughout the height of the resistive element.

Claims

1. A vertical-current-flow resistive element (12), comprising a monolithic region (12) having a first portion (12a) and a second portion (12b) arranged on top of one another, said monolithic region being formed by a single material and having a height greater than at least one other dimension, said first portion (12a) having a first resistivity, characterized in that said second portion (12b) has a second resistivity lower than said first resistivity.
2. The resistive element according to claim 1, wherein said first portion (12a) has a first concentration of species forming a prevalently covalent bond with said single conductive material, and said second portion (12b) has a second concentration of said species, lower than said first concentration.
3. The resistive element according to claim 2, wherein said species have a decreasing concentration starting from said first portion (12a) towards said second portion (12b).
4. The resistive element according to claim 3, wherein said first portion (12a) has an approximately constant resistivity.
5. The resistive element according to any one of claims 2 to 4, wherein said second portion (12b) has a gradually decreasing resistivity starting from said first portion (12a).
6. The resistive element according to any one of claim 2 to 5, wherein said conductive material is a binary or ternary alloy.
7. The resistive element according to claim 6, wherein said conductive material is chosen from among TiAl, TiSi₂, Ta, and WSi.
8. The resistive element according to any one of claims 2 to 7, wherein said species comprise nitrogen.
9. The resistive element according to any one of the foregoing claims, comprising a top electrode (15) of conductive material in electrical contact with said first portion (12a) and a bottom electrode (11) of conductive material in direct electrical contact with said second portion (12b).
10. The resistive element according to any of the foregoing claims, wherein said monolithic region (12) has a shape chosen from among a column shape, having a height, a width and a depth, wherein the height is greater than the width and the depth, a wall shape, having a height, a width and a depth, wherein the depth and the height are greater than the width, and a closed shape having a height, a width and a perimeter, wherein the height and the perimeter are greater than the width.
11. A phase-change memory element (10) comprising a resistive element (12) and a programmable element (13) of chalcogenic material in direct electrical contact with a top end of said resistive element, characterized in that said resistive element (12) is manufactured according to any of claims 1 to 10.
12. The resistive element according to claim 11, wherein said programmable element (13) is formed by a strip of polycrystalline material (13) extending, at least in proximity of said resistive element, in a preset direction, and wherein said width extends in said preset direction.
13. A process for manufacturing a vertical-current-flow resistive element, comprising the step of: forming a monolithic region (12) of conductive material having a uniform resistivity and having a first portion (12a) and a second portion (12b) arranged on top of one another, characterized by the step of increasing the resistivity of said first portion (12a) so that said first portion (12a) has a greater resistivity than said second portion (12b).
14. The process according to claim 13, wherein said

step of increasing the resistivity comprises enriching said first portion (12a) with species that form a prevalently covalent bond with said conductive material.

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15. The process according to claim 14, wherein said step of enriching comprises implanting or introducing said species from plasma.
16. The process according to any one of claims 13 to 15,
wherein said conductive material is a binary or ternary alloy.
17. The process according to any one of claims 13 to 16,
wherein said conductive material is chosen from among TiAl, TiSi₂, Ta, and WSi.
18. The process according to any one of claims 14 to 17,
wherein said species comprise nitrogen.
19. The process according to any one of claims 13 to 17, further comprising the steps of forming a bottom electrode (11) of conductive material in direct electrical contact with said second portion (12b) and forming a top electrode (15) of conductive material in electrical contact with said first portion (12a).

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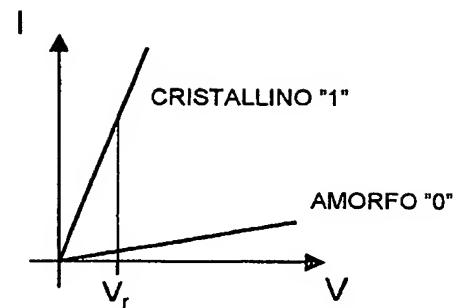


Fig. 1

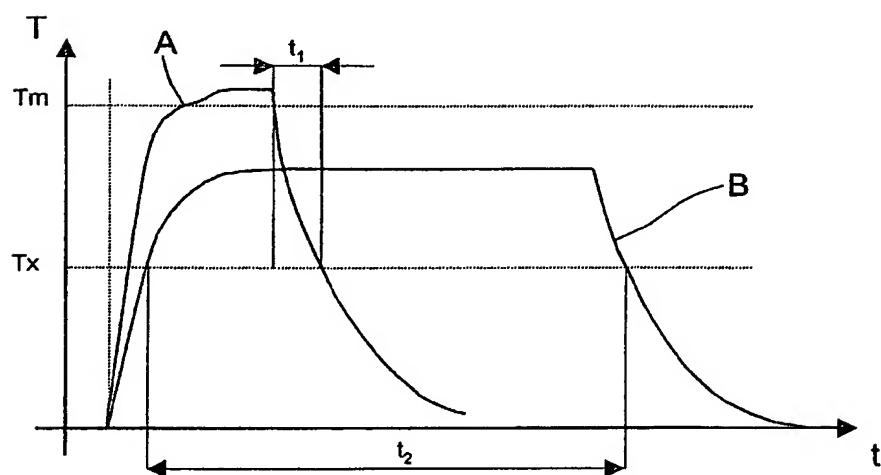


Fig. 2

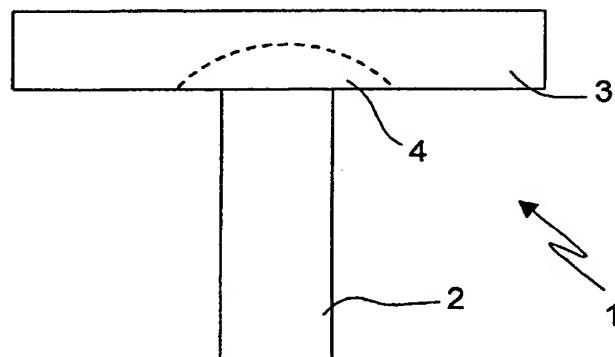


Fig. 3

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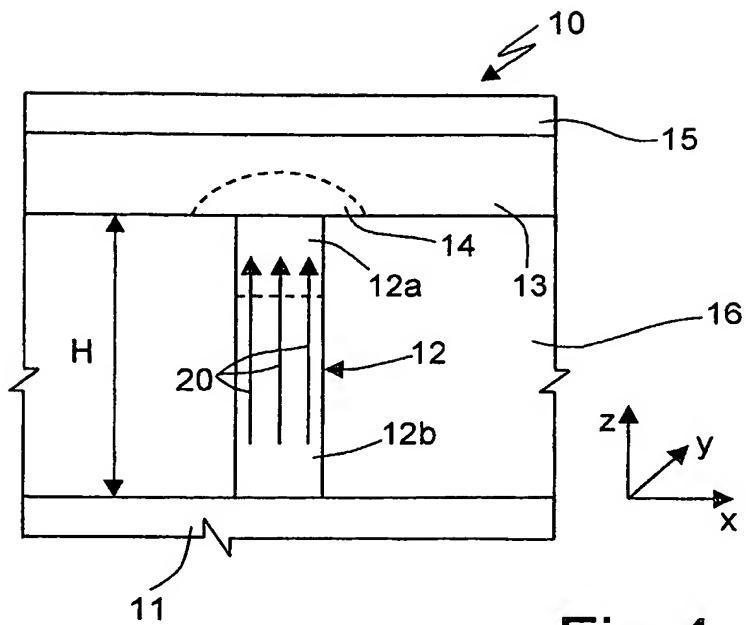


Fig.4

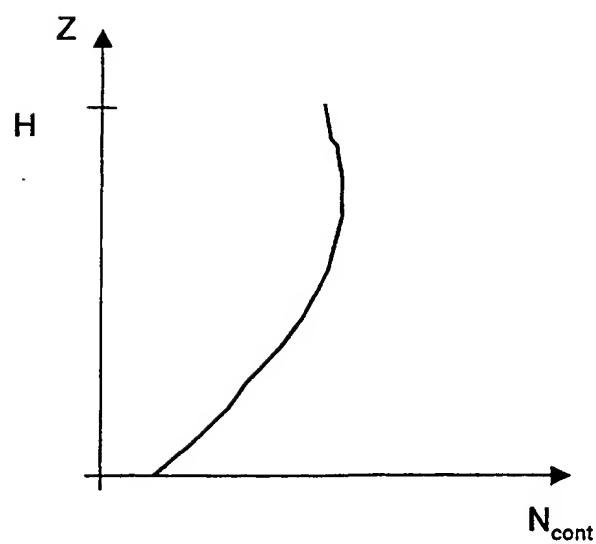


Fig.5

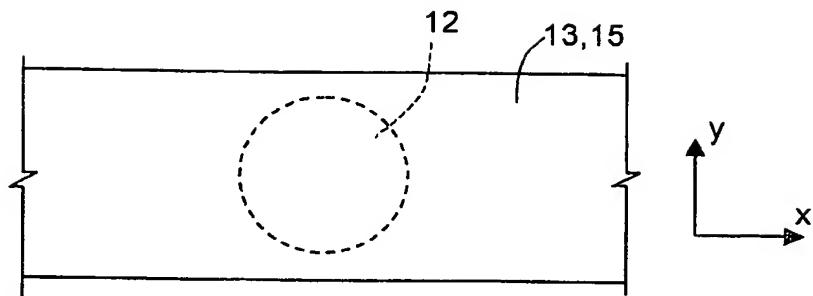


Fig.6

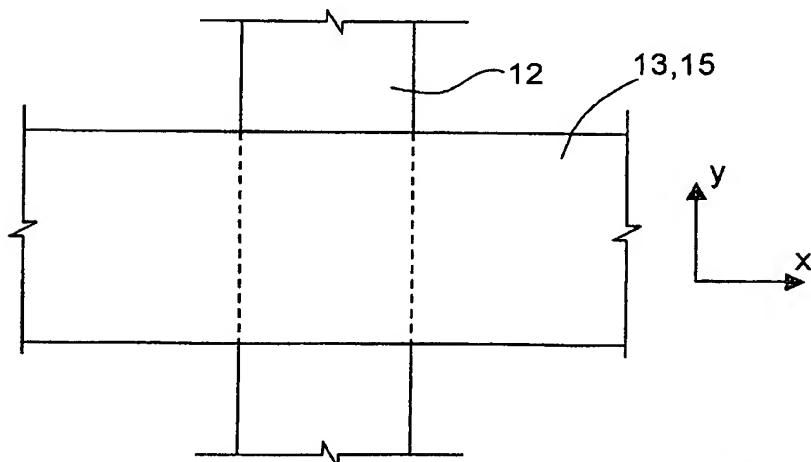


Fig.7

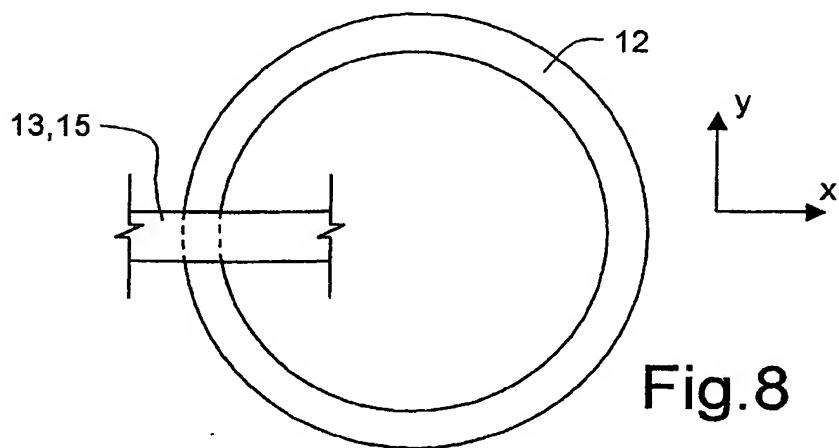


Fig.8



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EUROPEAN SEARCH REPORT

Application Number
EP 02 42 5013

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.7)
E	<p>WO 02 09206 A (OVONYX INC) 31 January 2002 (2002-01-31)</p> <p>* page 5, line 4 – line 12; figures 1D, 1E * * page 21, line 9 – line 21 * * page 18, line 16 – line 24 * * page 22, line 7 – line 23 * * page 29, line 1 – line 16 * * page 5, line 4 – line 12 * * page 81, line 24 – page 82, line 8; figures 1D, 1E *</p> <p>-----</p>	1-5, 11-15	H01L45/00
A	<p>US 5 687 112 A (OVSHINSKY STANFORD R) 11 November 1997 (1997-11-11)</p> <p>* column 13, line 17 – column 14, line 39 *</p> <p>-----</p>	1-19	
A	<p>US 5 714 768 A (WICKER GUY C ET AL) 3 February 1998 (1998-02-03)</p> <p>* column 6, line 48 – column 7, line 26 *</p> <p>-----</p>	1-19	<p>TECHNICAL FIELDS SEARCHED (Int.Cl.7)</p> <p>H01L</p>
<p>The present search report has been drawn up for all claims</p>			
Place of search	Date of completion of the search	Examiner	
MUNICH	3 June 2002	Frias Rebelo, A	
CATEGORY OF CITED DOCUMENTS		<p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document</p>	
<small>EPO FORM 1503 03/92 (P94/00)</small>			

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 02 42 5013

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
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